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Modelling Railway Prestressed Concrete Sleepers (Crossties) With Holes and Web Openings

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Abstract

Pre-stressing in concrete railway sleepers yields endurance property under high-cycle fatigue. This structural effect plays a positive role in durability of the sleepers. However, as a common practice, track engineers often generate holes or web openings in concrete sleepers to enable the accommodation of rail equipment cables and signaling equipment. This study aims to provide a principle understanding of the structural capacity and energy toughness of pre-stressed concrete sleepers with and without holes and web openings. It will investigate the design criteria and effects of holes and web openings on the structural capacity of concrete sleepers under rail loading. The finite element modelling for ultimate strength design of concrete sleepers will be highlighted in this study. Static experimental investigations have been firstly carried out to validate the finite element models using ABAQUS. The models are capable of predicting the failure planes and can help provide practical guidelines for the holes and web opening for track engineers.

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Keywords: Prestressed concrete sleepers; numerical modelling; web opening; hole; railway crossties; finite element model.

1. Introduction

Railway sleepers are transverse beams laying on ballast and support to secure the rails and rail gauge, providing safe navigation of rolling stocks. Wooden sleepers were utilized as a part of the past in light of the fact that timber was

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promptly accessible in many regions around the globe. Nevertheless, pre-stressed concrete sleepers, and to a restricted degree of steel sleepers, have been well received in modern railway tracks over the previous decades on account of their strength and long administration life. Solid sleepers are depicted as either twin-square or mono-piece. Inside all these sorts, concrete sleepers are all the more generally utilized in light of the fact that they are not influenced all that much by either the atmosphere or climate. Furthermore, it provides anchorage for the fastening system and limit longitudinal, parallel and vertical movement by embedding itself onto the substructures [1]. Fig. 1 below illustrates the two types of concrete sleepers.

Nomenclature

ρ_c	density of concrete
ρ_s	density of steel
v_c	Poisson's ratio of concrete
v_s	Poisson's ratio of steel
σ_{cc}	Compressive strength of concrete
σ_{ct}	Tensile strength of concrete
E_c	Modulus of elasticity of concrete
E_s	Modulus of elasticity of steel
CDP	Concrete damage plasticity
FEA	Finite element analysis
GF	Fracture energy
P	Prestressing force

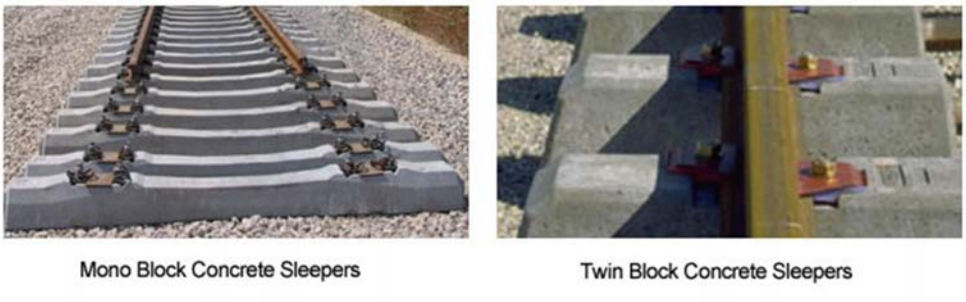

Fig. 1. Mono-block and twin-block concrete sleepers [2].

2. Significance and originality

Concrete sleepers (or crossties) were initially introduced around many decades ago and at present are introduced in almost everywhere in the world. Their major role is to distribute loads from the rail foot to the underlying ballast bed. Railroad track structures often experience impact loading conditions due to wheel/rail interactions associated with abnormalities in either a wheel or a rail [1, 3]. In addition, railroad track components are often being modified at construction sites to fit with signalling gears, cables, and additional train derailment protections, such as guard rails, check rails, Earthquake protection rails, etc. The practical guideline for crosstie retrofit has not been well established and many attempts were carried out based on empirical experience, and trials and errors. Despite a common task in construction site, the behaviour of holes and web openings on concrete crossties has not been well documented in open literature. In this manner, it is important to ensure that concrete sleepers can be retrofitted and modified for add-on fixture in practice [4-8]. The emphasis of this study has been placed on the numerical modelling of the sleepers with holes and web openings. The model can lead to better understanding of structural behaviours of the sleepers with holes and web openings, which will not only improve safety and reliability of railway infrastructure, but will also enhance the structural safety of other concrete structures.

3. Finite element modelling

A three-dimensional finite element package (ABAQUS) has been used to establish the 3D model, which is a numerical instrument used to show and simulate the mechanical behaviour and the responses of prestressed concrete sleepers. At present, it is important to be able to use very advanced mathematical solutions and methods for virtual analyses of large and complex structures, of which the experimental work would be very expensive and time consuming. Therefore, finite element analysis (FEA) has become a very famous tool in the recent years. It provides numerical answers for even extremely complex stress issues, which can now be acquired routinely utilizing FEA packages. FEA packages were widely used for three main reasons, which are an effective cost of construction, saving in design time and finally, the safety of the structure [9-11].

ABAQUS/CAE version 6.11-2 has been chosen as the fundamental stage for this study. All solid component models have been created using ABAQUS. A complete investigation utilizing ABAQUS obliges a depiction of the nonlinear materials, the model setup, boundary conditions, relevant steps, element input and loading process. A three-point static bending test was undertaken in order to validate the model with the experimental results. The material non-linearity is essentially adopted for this model due to its plastic behaviour of concrete and steel after the fracture or yield point. This can be accomplished by entering the relevant linear and non-linear data for the material section in ABAQUS. For the linear structural behaviour of the material, elastic modulus and the Poisson's ratio are used. Concrete damaged plasticity model in ABAQUS/Explicit has been used for modelling pre-stressed concrete sleepers with hole and web opening as shown in Fig. 2 [12-14].

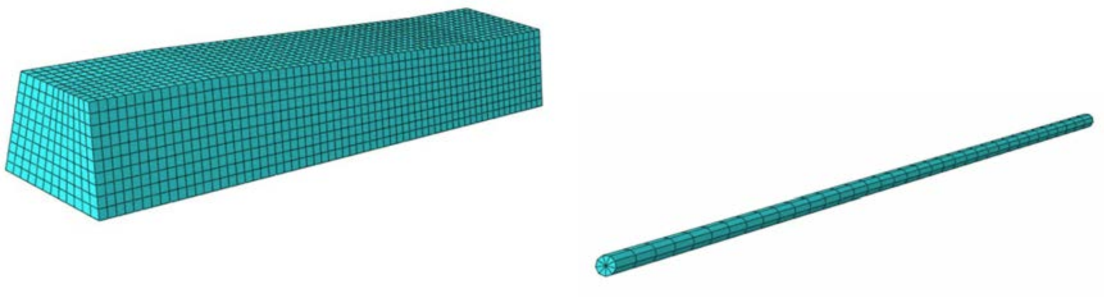

Fig. 2. Constructed meshes of concrete sleeper and a prestressing steel tendon (not on scale).

The typical properties of normal strength concrete C60 used as input data:

- Density: ρ_c = 2400 kg.m^{-3}
- Young's modulus: E_c = 36406 MPa
- Poisson's ratio: v_c = 0.2
- Compressive strength: σ_{cc} = 60 MPa
- Tensile strength: σ_{ct} = 2.85 MPa
- Fracture energy: GF = 154 N/m

The compressive behavior of concrete was established through the plasticity algorithm and compressive stress-strain data in order to obtain the crushing effect of concrete. The tensile behavior of concrete was attained by the yield stress and the fracture energy input. Table 1 below illustrates the material parameters of concrete damage plasticity (CDP) model for concrete compressive strength of 60 MPa.

Table 1. Plasticity input for CDP model.

Property	value
Dilation angle	45
Eccentricity	0.1
F_{b0}/f_{c0}	1.16
K	0.0067
Viscosity parameter	0

Pre-stressed tendons in a sleeper can increase tensile capacity of the sleeper. It is important to consider the pre-stressed steel material data when modeling. The properties of the pre-stressed steel tendons are as follows:

- Density: ρ_s = 7.8 g.cm^{-3}
- Young's modulus: E_s = 200 GPa
- Poisson's ratio: v_s = 0.3
- Prestressing force: P = 68 kN

4. Experimental validation

The test setups have carried out in accordance with British Standards: BS EN 13230-2:2009 [4], in order to provide benchmarking type-testing results as shown in Fig. 3. The testing was undertaken using displacement control method at a slow load rate in order to obtain more accurate data. The equipment used for the test are as follows:

- Strain gauges and wires at top and bottom fiber (25 mm) and strain gauge bridges;
- Load cell;
- Linear potentiometer at the neutral axis and top of the sleeper; and
- Computer and data logger (DATA LOGGER SQUIRREL 2040 USB).

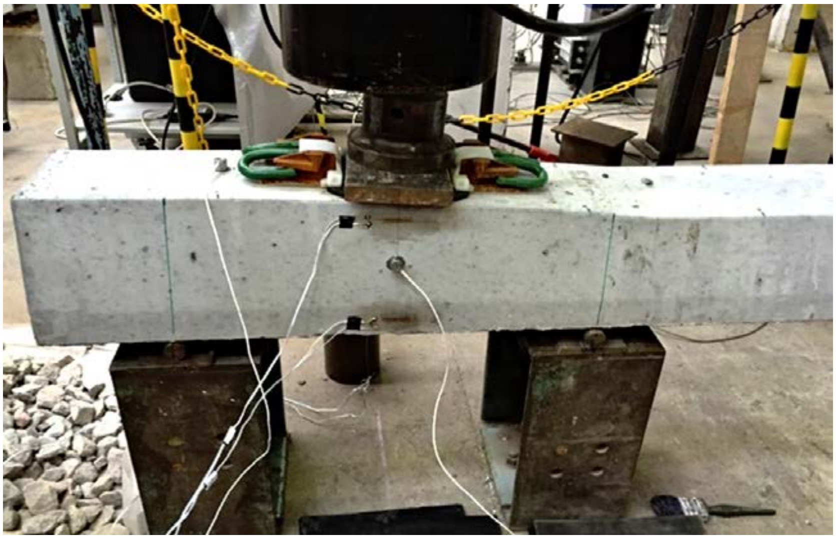

Fig. 3. Arrangement at the rail seat for positive bending test.

Fig. 4 demonstrates the load-deflection comparison of the experimental and numerical results for the sleeper with no web openings. The elastic range of the two curves shows good correlation with failure. In addition, the numerical ultimate load obtained from FEA is 2.2 % lower than the maximum experimental load for the applied displacement. However, the numerical results show an early failure at around 5mm deflection compared to the experimental results.

This is because only available tested parameters for concrete damage model introduced in the model are for reinforced concrete structures.

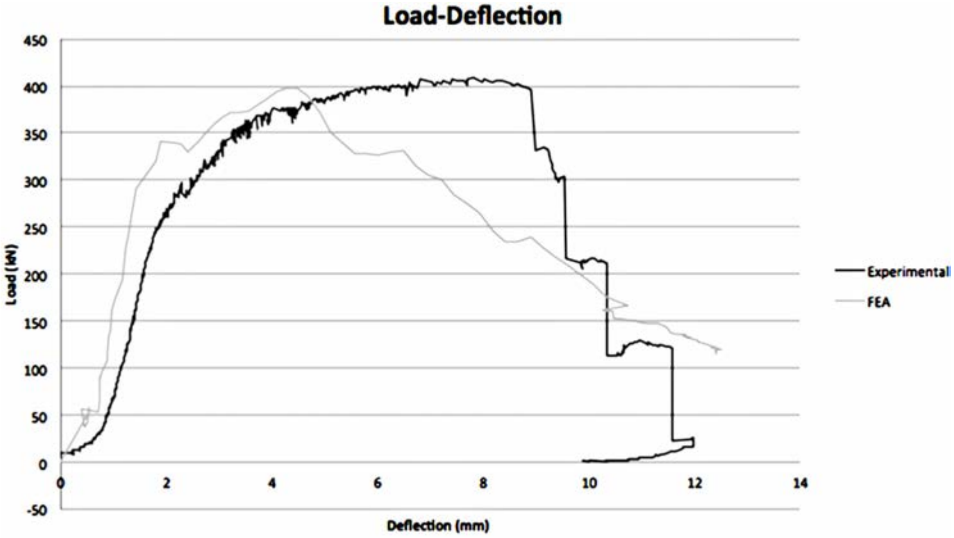

Fig. 4. FE validation of the sleeper with no web openings.

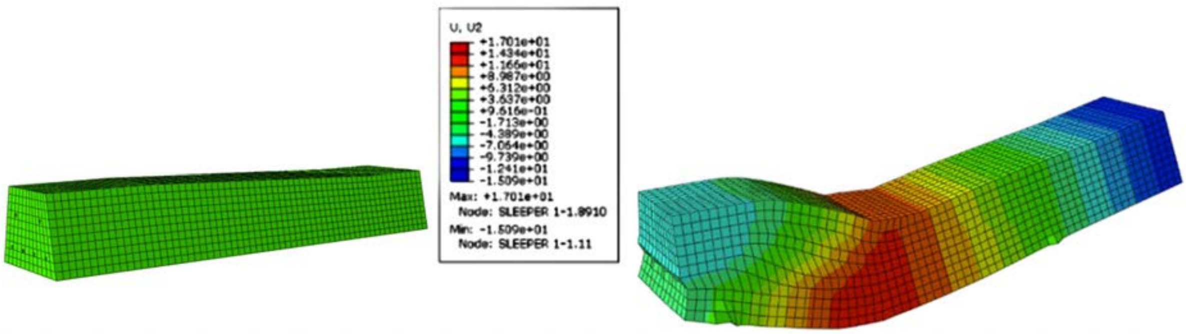

Fig. 5. Deformed shape of the sleeper with no web openings.

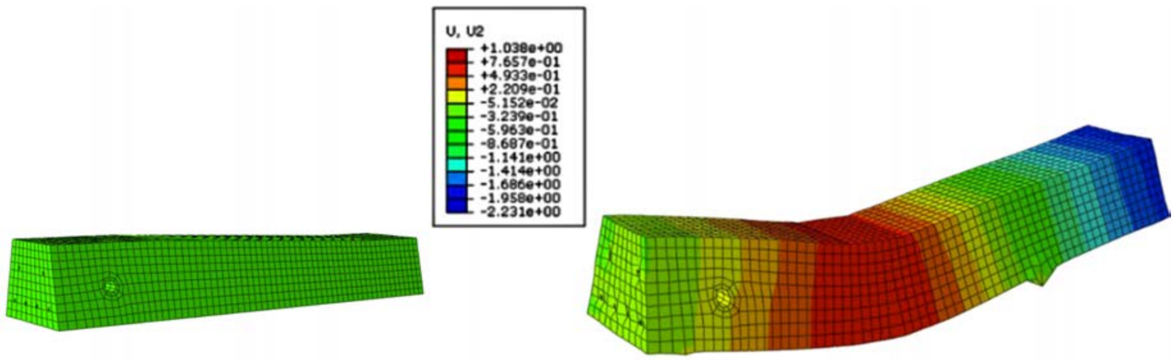

Fig. 6. Deformed shape of the sleeper with 32mm transverse hole.

5. Results and discussion

Fig. 5 illustrates the initial stage and the deformed stage of the pre-stressed concrete sleeper with no web openings. The maximum deflection obtained from the experimental data, which is 13mm was applied to the rail seat position as boundary condition as shown in Fig. 5. The load-deflection curve will be plotted from obtained deflection. The total force will be calculated from the two reaction forces from the roller supports. These two reactions will be summed up together in order to obtain the total force for the applied displacement. Figs 6 and 7 illustrate the initial stage and the deformed stage of the pre-stressed concrete sleepers with 32mm transverse hole and 32mm vertical hole, respectively.

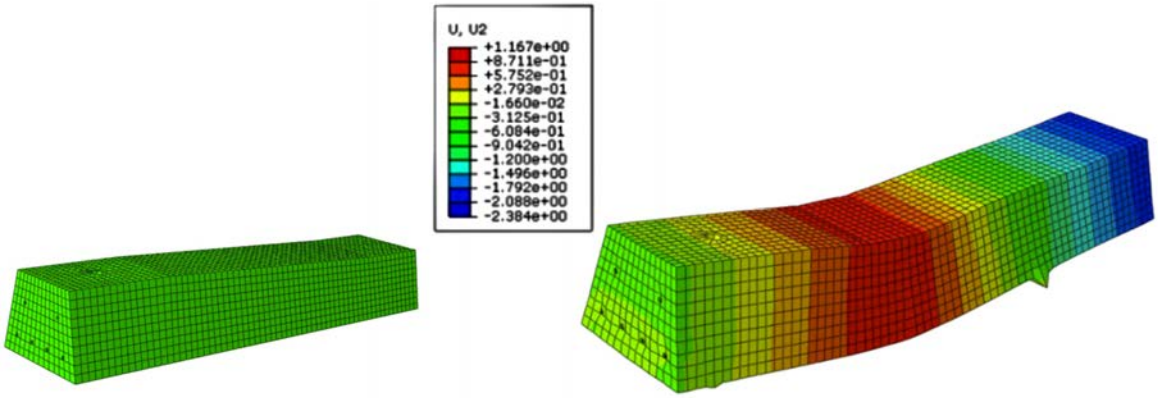

Fig. 7. Deformed shape of the sleeper with 32mm vertical hole.

6. Conclusions

This paper presents original and rigorous numerical investigations into the structural behaviors of railway prestressed concrete sleepers with holes and web openings. As a common practice, track engineers often generate holes or web openings in concrete sleepers to enable the accommodation of rail equipment cables and signaling equipment. This study aims to provide novel advanced modeling for determining structural capacity and energy toughness of pre-stressed concrete sleepers with and without holes and web openings. The finite element modelling for ultimate strength design of concrete sleepers has been established and validated using experimental results. The comparison between numerical and experimental results exhibits excellent agreement and thus suggests that the models are capable of predicting the failure planes and can help provide practical guidelines for the holes and web opening for track engineers. Future work includes the prognostic and damage identification of railway prestressed concrete sleepers using acoustic emission and modal analysis [15].

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